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Improving substance use prevention efforts with executive function training

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ABSTRACT

Background: Executive function (EF) includes emotional regulation, planning and decision-making, and behavioral impulse control. Improving youth substance use (SU) prevention by targeting EF poses challenges including determining whether specific sub-domains of EF are more associated with SU than others, whether EF is related to some types of SU more than others, and whether EF programs might be enhanced by inclusion of mindfulness training.

Methods: Data were drawn from two studies from the Pathways to Health project: a randomized controlled trial of 4th–6th graders and a cross-sectional pilot study of the relationship of EF to specific types of SU in a sample of 7th graders. Survey measures included assessment of the EF subdomains of inhibitory control (IC), emotional control, working memory, organization/planning, lifetime SU (tobacco and alcohol use), and mindfulness. Analyses included multivariate and multiple group path analysis.

Results: Results suggested that the EF sub-domain of IC was the strongest and most consistent predictor of SU, particularly cigarette and e-cigarette use, though emotional control was predictive of alcohol use among late-elementary school students. In the 7th grade sample, IC was predictive of alcohol, cigarette, and e-cigarette use only among students in the low 75% of mindfulness.

Conclusions: Findings from the present studies suggest that improvements in SU prevention efforts may result from increased curricular emphasis on IC and its application to multiple substance use prevention, and systematically integrating mindfulness with EF skills training. Future research should examine whether EF–SU relationships vary across patterns of SU and types of measures used to assess EF.

1. Introduction

1.1. Incorporating executive function (EF) into substance use (SU) prevention programs

Most SU prevention programs for adolescents are school-based and include some variation of social skills training with the intent to teach adolescents how to recognize and avoid peer pressure, and to make good decisions about selecting alternatives to drug use (Pentz, 2009). Such programs typically assume that once presented with an array of alternatives, adolescents will make the appropriate plans and decisions required to stay drug free. However, planning and decision-making represent only some of the skills that enable adolescents to select healthier alternatives to SU. Others include, but are not limited to, emotion regulation and impulse control (Bardo and Pentz, 2015; Romer et al., 2009). Collectively, these skills represent executive function (EF), the neurocognitive processes which guide health behavior and development in general (Pentz, 2009; Riggs and Pentz, 2015, in press).

There is increasing recognition that emotion regulation, impulse control, and the more "planful" aspects of EF proceed through rapid phases of integration during adolescence [i.e., as the pre-frontal cortex becomes integrated with both the dopaminergic mesolimbic (reward) and amygdala-striatal (emotion) systems of the brain] and, if underdeveloped, pose significant risk for early adolescent SU (Kandel and Kandel, 2014; Riggs et al., 2012a,b). This integration also informs the dual processing model of implicit and explicit cognition as it relates to SU addiction (Giancola and Tarter, 1999; Gibbons et al., 2009; Henderson et al., 2015). Thus concentrating only on higher-order cognitive skills such as planning or healthy

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goal-setting in prevention programs, rather than integrating these skills with emotional regulation and impulse control training, may not provide the full picture in understanding what drives adolescent risk for SU and how to reduce this risk.

1.2. Examples of prevention programs focused on EF

Recently, a small number of programs, typically focusing on behavioral outcomes other than SU prevention, have been shown to effectively promote EF in children (Diamond and Lee, 2011). For example, Promoting Alternative Thinking Strategies (PATHS) is a social-emotional learning program that has shown effects on childhood behavioral conduct problems mediated by program effects on EF (Riggs et al., 2006). More recently, EF training has been applied directly to SU prevention in children and early adolescents in the Pathways to Health trial, which is described in this paper. The Pathways program is based on emotional regulation and behavioral impulse control skills training that are applied directly to situational and environmental contexts for SU, as well as obesity risk behaviors that have been similarly associated with emotional regulation and impulse control (Bardo and Pentz, 2015; Pentz, 2009; Riggs et al., 2006; Sakuma et al., 2012). Details of the Pathways program are published elsewhere (Pentz et al., 2015; Riggs et al., 2012a,b; Sakuma et al., 2012).

1.3. Remaining questions

It is not clear from current programs whether emotional regulation, behavioral impulse control (sometimes referred to as emotional control and inhibitory control in EF measurement), working memory, or higher order planning/organizational skills are driving most of the effect of EF skills training programs, nor whether EF competency is more closely linked to reduced risk for use of some substances vs. others., e.g. tobacco vs. alcohol use. Finally, there is increasing evidence to suggest that mindfulness can moderate the relationships of tobacco use intentions and distress to SU (Black et al., 2015a, 2012). However, little is known about whether mindfulness moderates the relationship of EF–SU, thereby potentially increasing the impact of EF training on SU.

Published studies on the Pathways program have thus far focused on development and effects of the Pathways program (Riggs et al., 2007; Sakuma et al., 2012), the relationship of EF to obesity risk behaviors and SU (Pentz and Riggs, 2013; Pentz et al., 2015; Riggs et al., 2012b), and whether the relationship of EF to SU is moderated by socioeconomic status (Riggs and Pentz, 2015, in press). Findings to date have raised several questions about how to improve subsequent substance use prevention programs. One is whether training on specific subdomains of EF might be differentially emphasized to increase program effectiveness. Pathways focused equally on all four domains of EF (global EF), without separation or emphasis on a particular domain. A second question is whether EF training might have a greater effect on certain types of SU than others, thereby informing which substance(s) might be the best targets for initial application and evaluation of EF training. A third question is whether including mindfulness enhances the practice of EF skills (Pentz, 2014). While Pathways incorporated some exercises which may have bolstered mindfulness among participants, such activities constituted less than 5% of the program and were not designed a priori to impact mindfulness. Furthermore, these exercises were applied only in the early stages of the program where emotion recognition and regulation were addressed. To examine these questions, the present paper draws on data from two studies that were part of the Pathways to Health Project: a prevention trial on 4th-6th graders, and a cross-sectional pilot study of 7th graders.

2. 4th–6th grade pathways to health prevention trial

The 4th–6th grade Pathways to Health prevention trial was a randomized controlled trial involving matching and randomization of 4th grade students from 28 elementary schools to either a 30 session teacher-delivered EF training program delivered over a three-year period, or a delayed intervention control group (2008–2014). Pathways was based on a theoretical model that included promoting EF skills related to both emotion regulation and behavior control as applied to multiple health risk behaviors that were developmentally sequenced so that dietary intake, sedentary, and physical activity behaviors were addressed in 4th and 5th grade, with tobacco and alcohol use behaviors introduced in 6th grade (Pentz 2009; Sakuma et al., 2012). Also sequenced were the EF skills, with affective feelings and emotion regulation skills first, followed by decision-making and behavioral choices, behavioral applications, and finally, simultaneous and reciprocal practice of both affective and "planful" cognitive skills.

2.1. Sample

Of the 1005 students who formed a parent- and self-consented panel followed for 4 measurement periods and 3 years, 185 moved out their districts, 18 declined participation after baseline, 29 were absent from measurement, and 64 were excluded from analysis due to switching intervention conditions following school closure (4 of 28 schools were closed). The resulting analysis sample size was 709. Analyses showed few differences between retained participants with complete vs. incomplete data, with the exception that slightly more Hispanic ($p < .05$) and lower SES ($p < .001$) participants had incomplete data.

2.2. Measures

The Pathways trial used a self-report survey including measures of EF and lifetime tobacco and alcohol use (SU; none to one or more). Since Pathways was a field-based universal prevention trial with applications of EF training to everyday contexts for behavior, the Behavior Rating Inventory of Executive Function-Self-Report version was used to measure EF (Guy et al., 2004). The BRIEF consists of 8 scales with items that measure the application of EF in everyday situations. Three versions have been standardized on youth as young as 4th grade: teacher, parent, and self-report. Following procedures used in our previous studies, the BRIEF self-report form was used and EF was analyzed both as a global EF competency score as well as four separate subscales (Riggs et al., 2012a) that have shown the strongest predictive relationships to SU, specifically the emotional control (EC, 9 of 10 items), inhibitory control (IC, 11 of 13 items), working memory (all 12 items), and organization of materials (all 7 items) subscales (Guy et al., 2004). For each item on each subscale, participants were asked "How often each of the following has been a problem in the last month?" BRIEF response choices were: 1 = Never, 2 = Sometimes, 3 = Often. An example item for the BRIEF EC subscale is "I have angry outbursts," and for the IC subscale is "I get out of control more than my friends." The BRIEF has shown acceptable internal consistency and concordance between subscales and global BRIEF scores (Riggs et al., 2007; Pentz and Riggs, 2013). Subscales are significantly correlated with one another (ranging from $r = 0.48$ to 0.64, p values < 0.001). The BRIEF also demonstrates good ecological validity (Guy et al., 2004).

SU consisted of two items drawn from the Monitoring the Future national survey on adolescent substance use: lifetime tobacco use and lifetime alcohol use, asked as "Have you ever smoked a cigarette in your whole life? (1 = no, not even a puff to 4 = use, 1 or more cigarettes) and "Have you ever tried alcohol in whole life (beer, wine, liquor not for religious purposes; 1 = no, not even a sip to

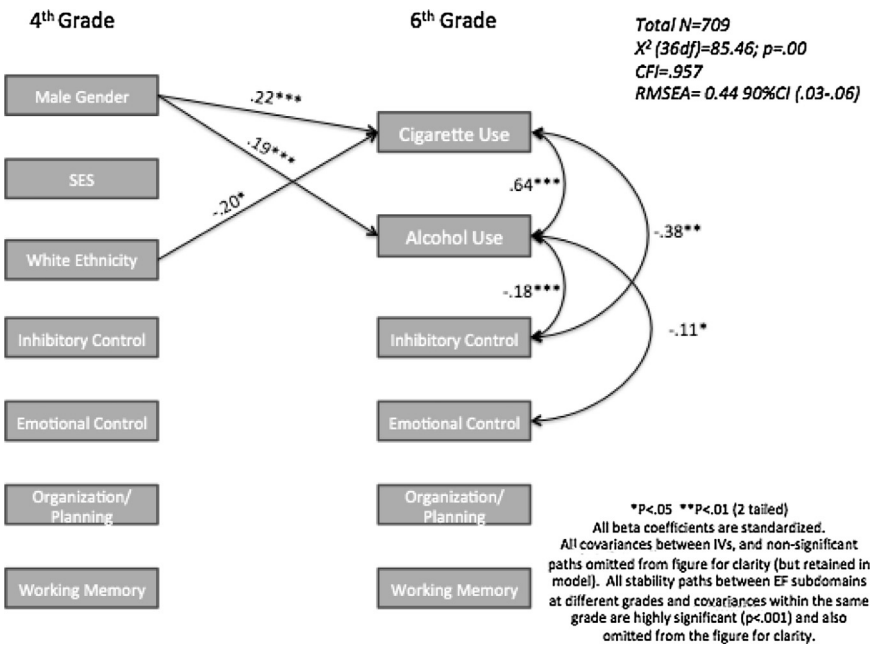

Fig. 1. Path model demonstrating relationships of inhibitory control, emotional control, working memory, and organization/planning to cigarette and alcohol use outcomes at 6th grade.

3 = yes more than a sip). Items were re-coded 0 (no use) to 1 (any tobacco or alcohol use) to create the SU score.

2.3. Analysis plan

Multivariate path analysis was conducted in order to evaluate associations between each of the four EF subscales and substance use at 6th grade, adjusting for gender, ethnicity (white vs. other), and free lunch (eligible vs. not) based on previous work linking these demographic characteristics to SU (Pentz et al., 2015; Riggs and Pentz, 2015, in press). This cross-lagged model was fit incorporating each of the four EF subscales at 4th and 6th grade as well as both cigarette and alcohol use outcomes into a single model. A robust maximum likelihood estimator was utilized which adjusted for clustering of participants within 24 schools. Program vs. control group assignment was originally included in these models but was omitted once it was determined that its inclusion did not significantly contribute to overall model fit or alter the strength of associations between study variables. The final model (Fig. 1) demonstrated a good fit to the data: CFI = .957; RMSEA = .44, 90% CI (.03–.06). All analyses were conducted using MPlus 7.4.

2.4. Results

Table 1 reports findings from the 709 youth who had complete data from 4th through 6th grade during the Pathways to Health trial. Of the four EF subscales reassessed at 6th grade, IC ($B = -.18$; $p < .001$) and to a lesser extent, EC ($B = -.11$; $p < .05$), were significantly associated with alcohol use by 6th grade. At 6th grade, only IC was significantly associated with cigarette use ($B = -.38$; $p < .01$). None of the subscales assessed at 4th grade significantly predicted 6th grade substance use. Males were more likely to report use of both alcohol ($B = .19$; $p < .001$) and cigarettes ($B = .22$; $p < .01$) by 6th grade.

3. Pilot study of 7th graders

3.1. Methods

A cross-sectional pilot study of 7th grade students was conducted in 2014 on an independent sample of two schools that were not part of the Pathways trial. Previous results of this pilot study showed that EF exceeded peer influence in importance as a risk factor for substance use (Pentz et al., 2015), low socioeconomic status moderated the effect of EF on SU (Riggs and Pentz, 2015, in press), and that mindfulness attenuated the impact of EF on stress and health risk behavior outcomes (Black et al., 2015b). The aim of the present study using the pilot data was to expand the current Pathways theoretical model to include mindfulness.

3.2. Sample

Of the total enrollment in these two schools ($N = 496$), 410 had parental consent and self-assent (82.7% of eligible; 22 absent from measurement, 23 with parental decline, and 41 with administrative decline due to scheduling conflicts). The 7th graders had a mean age of 12.5 years, 48.3% were female, 45.1% were White, 25.4% Hispanic, 14.9% mixed/bi-racial, 14.6% other; and 34.9% were on free lunch (an indicator of low socioeconomic status). After listwise deletion of cases with large amounts of missing data, the final analysis sample was 405.

3.3. Measures

The 7th grade pilot study utilized lifetime cigarette, e-cigarette, and alcohol use measures from the Monitoring the Future national survey on adolescent substance use (Johnston et al., 2014; PATH survey, NIH, 2014), EF (Guy et al., 2004), and trait mindfulness (Black et al., 2015b; Brown and Ryan, 2003). Lifetime use of each substance was coded as 0 or 1; mindfulness was treated as the reverse-coded mean of the 15 item MAAS scale, so that greater values reflect greater mindfulness. Mean mindfulness scores ranged from 1.3 to 6.

Table 1
Results from cross-lagged path model using 4th and 6th grade executive function to predict 6th grade tobacco and alcohol use ($N = 709$ students; standardized results).

Model estimates	Standardized parameter estimates for alcohol use paths (standard errors)	Standardized parameter estimates for cigarette use paths (standard errors)
→4th grade inhibitory control	−.11 (.08)	.02 (.13)
→4th grade emotional control	.11 (.08)	−.07 (.10)
→4th grade organization/planning	−.04 (.08)	−.07 (.10)
→4th grade working memory	−.01 (.07)	.11 (.1)
→6th grade inhibitory control	−.18 (.06)***	−.38 (.14)**
→6th grade emotional control	−.11 (.05)*	−.05 (.10)
→6th grade organization/planning	−.02 (.05)	.12 (.10)
→6th grade working memory	−.01 (.05)	.03 (.09)
→Male gender	.19 (.05)***	.22 (.05)***
→SES	.01 (.06)	.14 (.08)
→White ethnicity	−.02 (.70)	−.20 (.09)*

All stability paths between EF subdomains at different grades and covariances within the same grade were highly significant ($B = .36–.60$; $p < .001$ for all).
Model information: estimator = ML with cluster robust standard errors by classroom ($N = 24$); RMSEA .44; CFI = .957; exogenous variables were allowed to freely covary
* $p < .05$.
** $p < .01$.
*** $p < .001$.

3.4. Analysis plan

Multivariate path analysis of the moderating effects of mindfulness on the relationship between each of the four EF subscales and the three SU outcomes was conducted using a multiple group approach. Initial sensitivity analyses were conducted varying treatment of mindfulness as continuous, quartile, and mean split scores in regression. The greatest sensitivity was obtained by treating mindfulness as a dichotomous variable (high quartile vs. low three quartiles), which was utilized in the final model. The path model demonstrated excellent fit to the data: CFI = .990; RMSEA = .034, 90% CI (.00–.07). All analyses were conducted using the same software and set of covariates (gender, SES, white ethnicity vs. other) used in the prevention trial analysis. School 1 vs. 2 was also entered as a dichotomous covariate, but did not significantly impact model estimates and thus was removed.

3.5. Results

Fig. 2 shows differing relationships between EF and SU based on participants' level of mindfulness. Separate coefficients were estimated for participants in the upper quartile of mindfulness and the lower 3 quartiles, both of which are displayed on the corresponding path in Fig. 2. Table 2 reports standardized beta coefficients for key associations of interest. Among the low mindfulness group, IC significantly predicted all three types of substance use ($B_{\text{cigaretteuse}} = -.45$; $p < .001$, $B_{\text{alcoholuse}} = -.22$; $p < .05$, $B_{\text{e-cigaretteuse}} = -.46$; $p < .001$), whereas IC was only significantly associated with cigarette use within the high mindfulness group ($B = -.32$; $p < .001$). No other EF subdomain was associated with SU.

4. Conclusions and recommendations for applying ef to su prevention

Previous and current results show that greater IC skills in childhood are associated with significant reductions in cigarette use, alcohol use and e-cigarette use by early adolescence. The present findings argue for implementing EF training in elementary school as a means to prevent later SU, or providing better integration between social-emotional learning that addresses EF in elementary school with targeted SU prevention in middle school, particularly with regard to cigarette, and e-cigarette use. Results also suggest that while EF represents a range of processes and skills that integrate emotion regulation and behavioral impulse control, the latter – at least as measured by the BRIEF IC subscale – appears to have the strongest relationship to SU compared to other aspects of EF, including emotion regulation. Whether the relative strength of IC over EC is a reflection of the IC score's more proximal relation to observable SU behavior, potential overlap with EC, or a function of the BRIEF measure itself, is beyond the scope of the present paper. If future studies continue to support the strength of IC in predicting early adolescent SU and other health risk behaviors (Riggs et al., 2013), the results could inform the development of SU prevention programs that focus directly on behavioral impulse control.

4.1. Study limitations

There are several limitations to the present study. First, analyses were based on epidemiological relationships between EF and SU. Thus implications of how to more effectively design SU prevention programs are based on inference rather than intervention effects. Second, the studies presented here were limited in the sense that laboratory-based measures such as the Stroop were not feasible to use in our schools. The concurrent validity of everyday contextual measures, such as the BRIEF, with laboratory performance-based measures has been low to moderate (McAuley et al., 2010). However, in designing and evaluating a viable program that targets EF skills, the prevention researcher is faced with the challenge of which type of measure is most valid and reliable to use given the conditions and objectives of the study (McAuley et al., 2010; Toplak et al., 2013; Buchanan, 2015). The BRIEF was designed to assess EF in "real-life" situations (Guy et al., 2004) and can be administered to many participants simultaneously. Third, results were based on self-report survey measures. While Pathways included anthropometric teacher observation and parent report, these measures were not the focus of the present study.

4.2. Recommendations for improving SU prevention efforts

The present findings suggest that some tailoring of EF programs may be required depending on type of SU. For example, EF skills training might include more applications to cigarette and e-cigarette use, given the strong relationships identified here, or begin with cigarette and e-cigarette use applications and follow with applications to alcohol use and other SU in middle school. Future research might also consider whether the effectiveness of EF programs on SU prevention varies by level of SU (e.g., experimentation vs. regular use). With a young sample, the present study focused only on lifetime experimentation with two of the generally acknowledged gateway substances (tobacco and alcohol use).

An additional implication for designing better prevention programs is drawn from the mindfulness-EF–SU relationships found

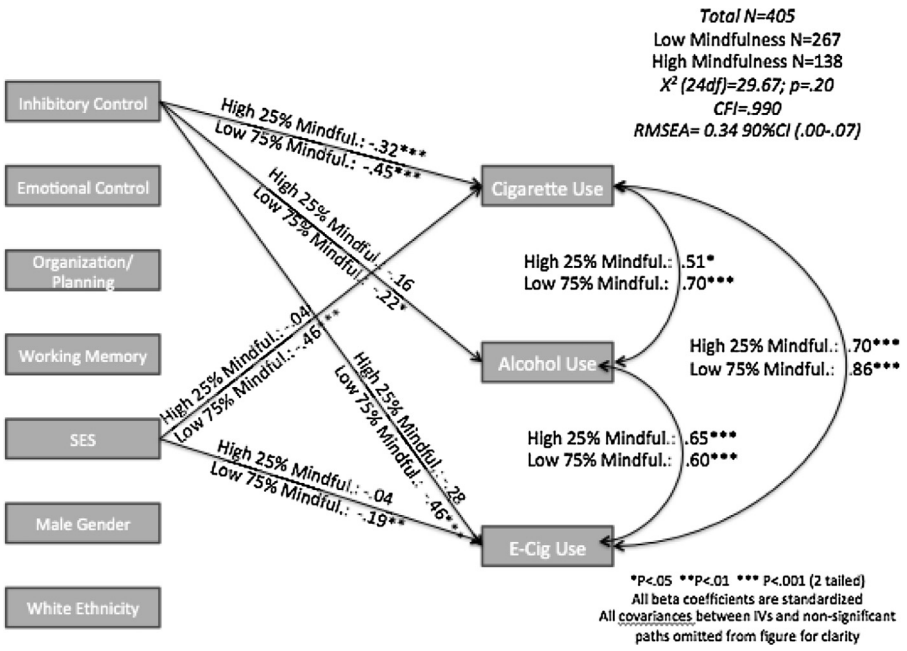

Fig. 2. Multiple group path analysis of relationships between EF subdomains, and SU types comparing high and low mindfulness groups.

Table 2
Results from path model of 7th grade data to examine cross-sectional association between EF subdomain competency and 7th grade cigarette, alcohol, and e-cigarette use (N = 405 students; standardized results).

Model estimates		Standardized parameter estimates for alcohol use paths (standard errors)	Standardized parameter estimates for cigarette use paths (standard errors)	Standardized parameter estimates for E-cigarette use paths (standard errors)	Standardized parameter estimates for paths correlating SU outcomes
Low mindfulness group					
	→Inhibitory control	−.22 (.10)*	−.45 (.11)***	−.46 (.10)***	
	→Emotional control	.09 (.09)	−.10 (.14)	−.08 (.11)	
	→Organization/planning	−.06 (.10)	.07 (.13)	.17 (.13)	
	→Working memory	.04 (.11)	.18 (.13)	.09 (.12)	
	→White ethnicity	−.07(.08)	.04 (.12)	−.19 (.10)	
	→SES	−.19 (.07)	−.46 (.08)***	.24 (.08)**	
	→Male gender	.14 (.08)	−.13 (.11)	−.04 (.10)	
	Cigarette use → alcohol use				.70 (.11)***
	E-cigarette use → alcohol use				.60 (.11)***
	E-cigarette use → cigarette use				.86 (.08)***
	All covariances among EF subdomains were highly significant (B = .29-.63; p < .001 for all)				
High mindfulness group					
	→Inhibitory control	−.16 (.13)	−.32 (.09)***	−.28 (.19)	
	→Emotional control	−.14 (.14)	.10 (.13)	.14 (.19)	
	→Organization/planning	.05 (.17)	.06 (.15)	−.15 (.16)	
	→Working memory	−.10 (.18)	.07 (.17)	.24 (.21)	
	→White ethnicity	−.08 (.12)	−.33 (.26)	.04 (.22)	
	→SES	.07 (.12)	.04 (.18)	−.03 (.22)	
	→Male gender	.08 (.11)	.06 (.23)	−.15(.17)	
	Cigarette use → alcohol use				.51 (.22)*
	E-cigarette use → alcohol use				.65 (.16)***
	E-cigarette use → cigarette use				.70 (.19)***
	All covariances among EF subdomains were highly significant (B = .44-.68; p < .001 for all)				

Model information: estimator = ML-robust; RMSEA .44; CFI=.957; exogenous variables were allowed to freely covary
* p < .05.
** p < .01.
*** p < .001.

in this study. Results, while cross-sectional, suggested that EF skills for SU prevention might be enhanced by including mindfulness training. The working hypothesis is that mindfulness *invokes* better practice of EF skills (Black et al., 2015a; Pentz, 2014). Future research might better address these relationships using longitudinal designs that vary inclusion of mindfulness in EF programs and also vary sequencing of mindfulness and EF skills applications.

Finally, previous and current study findings raise the question of what demographic or environmental factors may affect emotional regulation and EF development irrespective of prevention programs. One is low socioeconomic status, which appears to operate as a moderator of EF effects on health risk behaviors (Riggs and Pentz, 2015, in press). Another is male gender, which in our studies did not act as a moderator of EF or prevention effects, but which did elevate risk for SU among late-elementary school stu-

dents. Tailoring SU to situational contexts that may be gender or environment-specific have the potential to increase the effectiveness of current prevention programs based on EF skills training.

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Nothing declared.

Contributors

The authors each contributed to the conceptualization, writing, and editing of this paper.

Conflict of interest

The authors claim no conflict of interest.

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